Automated Design of Integrated Mixed Signal Microsystems (NeoCAD)

Background: Shrinking device sizes and higher integration densities are giving rise to a number of new challenges in designing the next generation of integrated electronic and optoelectronic circuits and systems. With the advent of the System-on-a-chip (SOC) technology, it is anticipated that mixed signal (digital, analog and software) and mixed technology (MEMS, fluidics, chemistry, biology, etc.) systems will necessitate new design strategies and methodologies. Current Electronic Design Automation (EDA) tools suffer from a number of limitations in addressing the above issues. Furthermore, it is anticipated that planned commercial investments in the above areas will not satisfactorily address military needs. One example is the analog to digital (A-D) converter for military applications: these systems suffer from severe on-chip electromagnetic (EM) interactions that lead to oscillations and loss of performance. The extreme wideband operation, high clock rates, high internal gains and high complexity (in number of transistors) make the design of such systems very laborious and time consuming.

Objective: DARPA is interested in exploring the feasibility of developing a new generation of CAD tools to enable the design of gigascale integrated mixed signal circuits/systems for military applications. NeoCAD research will investigate innovative approaches that enable revolutionary improvements in design automation for mixed signal (digital/analog/RF) and mixed electronic-photonic systems. One of the important goals of the NeoCAD program is the development of automated design tools and integrated design flow methodologies that demonstrate orders-of-magnitude reduction in design cycle time and/or cost for military systems.

Approach: Areas of research include:

I. **Fast Methods for Extraction of Parasitics:** Mixed signal systems (especially the analog components/circuits) are extremely sensitive to noise (electromagnetic, thermal, etc.) and cross-talk (e.g. switching noise) generated during the operation of the circuit. The design and optimization of mixed signal components and circuits require careful and detailed consideration of (linear and non-linear) system response to parasitics that could potentially affect the integrity of the signal. This area calls for the development of innovative fast solvers to perform linear and non-linear analysis of phenomena such as substrate coupling, transmission line effects, thermal noise, etc. Novel breakthrough advancements in fast algorithms will be implemented for the non-linear analysis of parasitics. Fast, accurate and automated extraction of parasitics from circuit layout will be an important deliverable for this area.

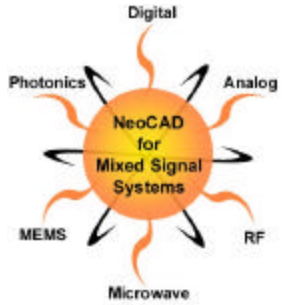
II. **Automated Model Order Reduction for Creation of Behavioral Models:** This task will develop innovative ideas for linear and non-linear automated model order reduction techniques for mixed signal and mixed electronic-photonic components and sub-systems. This includes the development of

accurate device/component models that account for new device architectures and materials that are finding applications in mixed signal systems. This area also calls for the development of methods that enable the creation of behavioral models and model libraries for mixed signal components and circuits and the ability to efficiently include the effects of parasitics on the behavioral models. A key deliverable for this area will be the demonstration of behavioral models and libraries in enabling a VLSI-like (i.e., a HDL-based top down design) approach for mixed signal and mixed electronic-photonic circuits.

III. **Automated Synthesis and Design Flow Methodology:** This area calls for the development of an integrated design environment to enable the automated synthesis of mixed signal and mixed electronic-photonic circuits. Novel and innovative ideas will be implemented to translate high-level design descriptions into reliable layout and gate level representations. Also of interest are methods for (i) integrating analog and digital design flows in mixed signal design, (ii) circuit simulation (in time and frequency domains) and optimization, (iii) design verification of mixed signal and mixed electronic-photonic circuits, and (iv) incorporating foundry-specific models to generate process and layout information (masks) for fabrication of mixed signal circuits. An important deliverable for this area is an automated design flow methodology that enables the designer to go from a design specification to a layout/process definition in minimum time.

NeoCAD will address the above areas in the context of mixed signal (digital/analog/RF) systems and/or mixed electronic-photonic systems. Development efforts will target enabling design capabilities for microsystems of interest and relevance to DoD. Examples of systems of interest to the military include (i) high performance analog-to-digital (A-D) converters operating at high clock rates (up to 10s of GHz), with wide dynamic range and high complexity (up to tens of thousands of transistors), (ii) integrated VCSEL-detector arrays and related optoelectronic components with controlling CMOS circuitry, and (iii) other relevant high performance microsystems integrating electronics, photonics and MEMS for sensing, communication and processing applications. NeoCAD projects will result in integrated design flow methodologies that demonstrate improved performance (in terms of overall design cycle time/cost) on the order of 10x or more over those of current mixed signal design methodologies.

This effort will form the groundwork for advanced CAD tools for routine analysis and design of mixed signal microsystems. The development of CAD tools for these applications will address a specific need of the military in being able to design high performance systems affordably. These CAD tools will also have direct commercial relevance to (1) Wireless Communication Devices (Mixed Digital/Analog Systems), and (2) Optical Devices consisting of Integrated Electronic/Photonic Systems as well as Micro-Opto-Electro-Mechanical Systems (MOEMS).



Design Methodology for Integrated Mixed Signal (A-D) and Mixed Electronic/Photonic Systems (NeoCAD)

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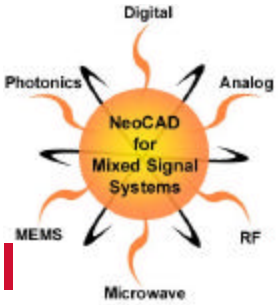
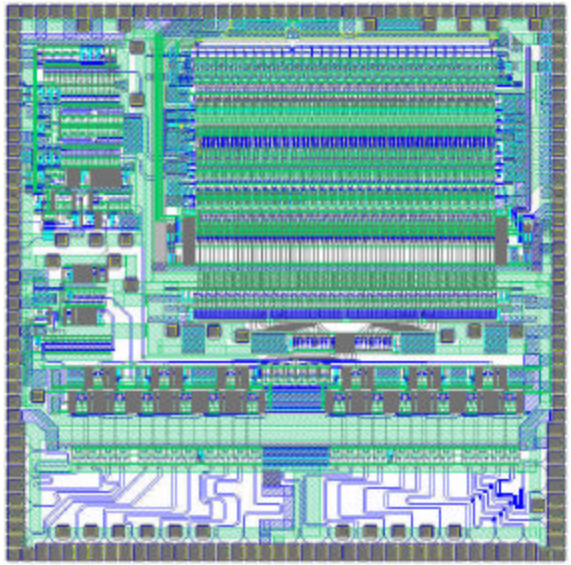
DARPA/MTO

Program Objective

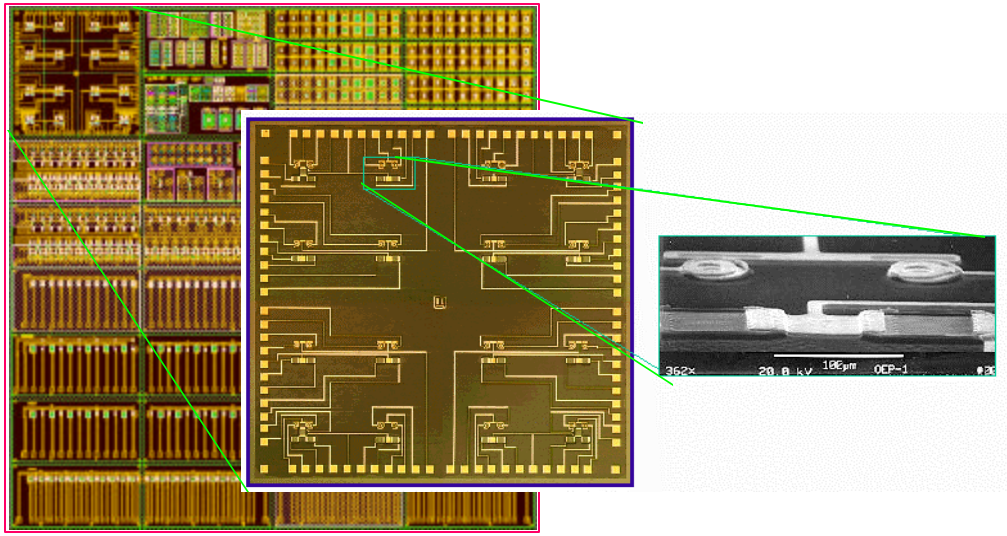


Automated Design of Integrated Mixed Signal (Analog- Digital) and Mixed Electronic/Photonic Systems for Military and Commercial Applications

Advanced Digital Receiver Chip (A-D and D-A Converters)

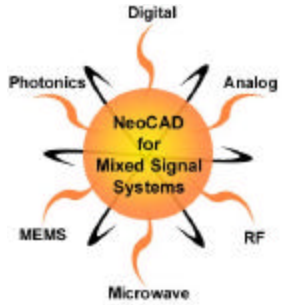


Integrated VCSEL-Detector Arrays



Tools to Enable Automated Synthesis of Mixed Signal Microsystems

Current Approach



Digital Design

- Top down design
- Behavioral (HDL) models for top level analysis
- Automated tools for chip layout and gate level description
- Limited real world physics !!

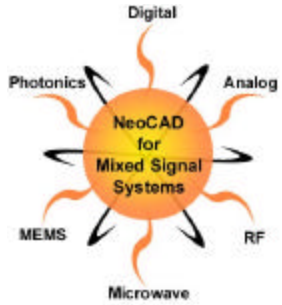
Automated Design Process, High Design Complexity (~ 10M Devices)

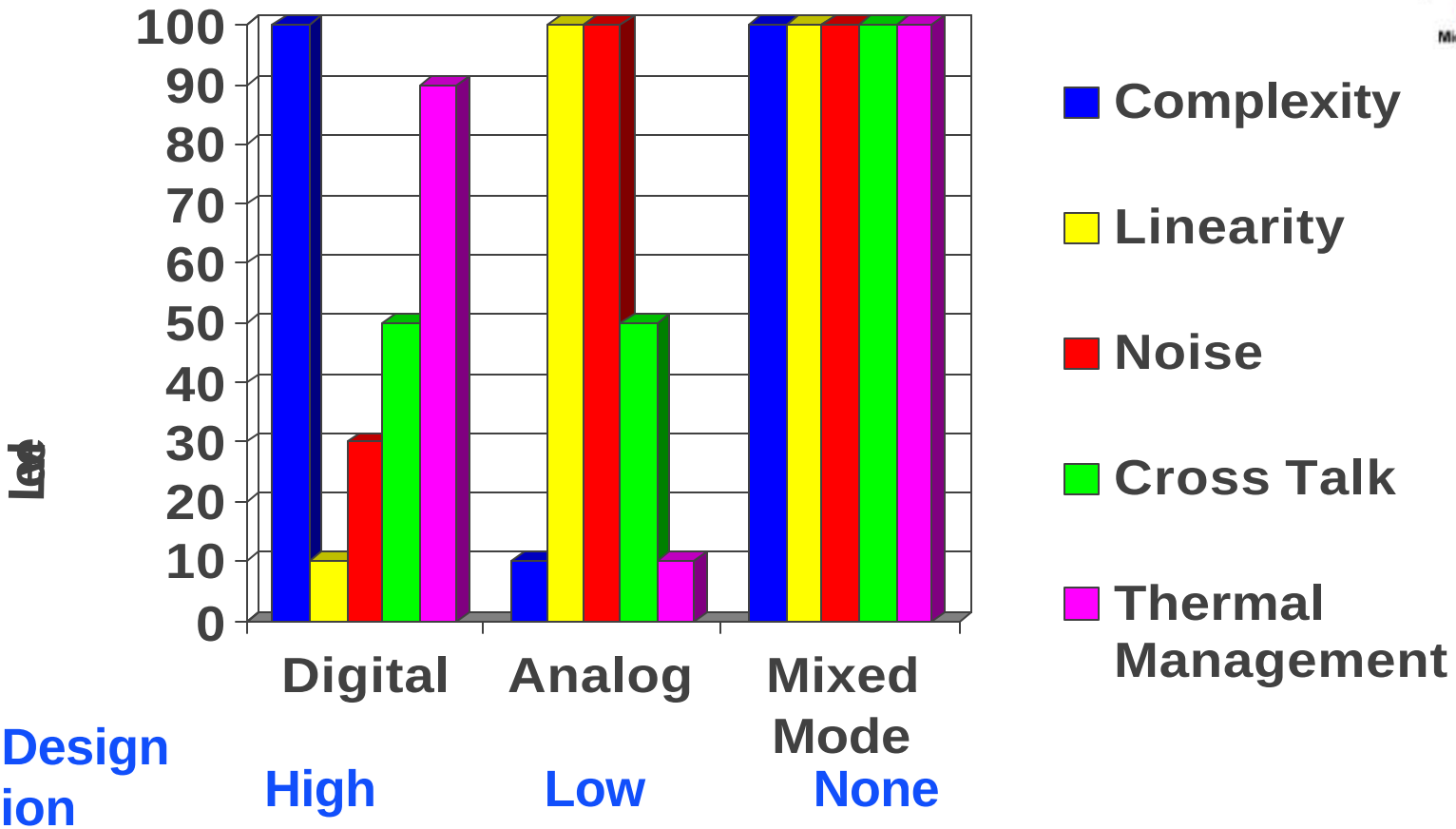
Analog/Photonic Design

- Bottom-up design
- Starts with component optimization
- Behavioral models and automation do not exist
- Dominated by physics (EM Coupling, frequency dependence, transmission line effects, temperature effects, signal integrity, …)

Time-Consuming Design Process, Low Design Complexity (100 – 1000 devices)

The Mixed-Signal Design Problem



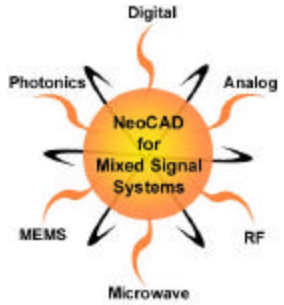


Level of Design Automation

High Low None

Mixed Signal Design Approach : Intuition and Experience
(Expert in the Design Loop – Not Automated !)
Photonic Design Approach: Largely Ad Hoc !

High Performance Mixed Signal Chip Development Cycle



Simulation

Simulation

Research

Circuit Design and Layout

3-9 months

Architecture

② Integrated Mixed Signals

① Innovative Designs

③ Advanced Technologies

f_T = 50 GHz - F1

f_T = 100 GHz - F2

Fab

3-4 months

Independent Test

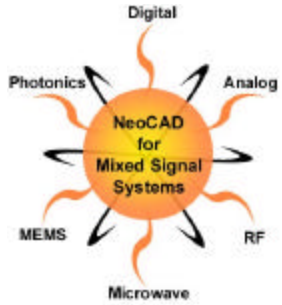
3 months

(Prototypes to other Programs)

Products

Typical Design Cycle Time ~ 2 Years

Defense vs. Commercial



Commercial Systems

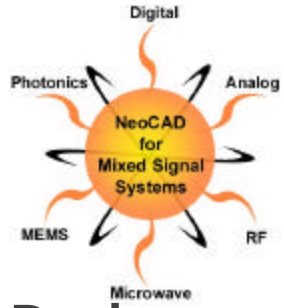
- 100 designers for one chip set, designers with highly specialized skills
- Product designed to be replaced in 18 months with perhaps 5 year lifetime
- Afford huge design verification effort for sales of 10^8 pieces
- ROI drives market timing

Military Systems

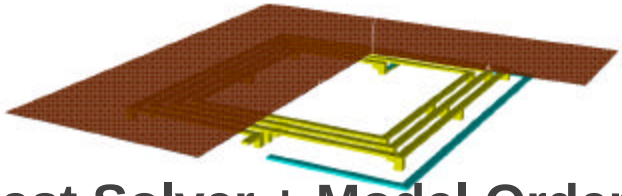
- 2,500 engineers for 1,500 contracts, few designers with broad range of skills
- 30 year platform lifetimes
- Tough to amortize over 1,000 pieces
- Mission need/doctrine/threat response drives market timing

Military Applications Demand Design Automation to Realize High Performance Systems at Reduced Cycle Times/Costs

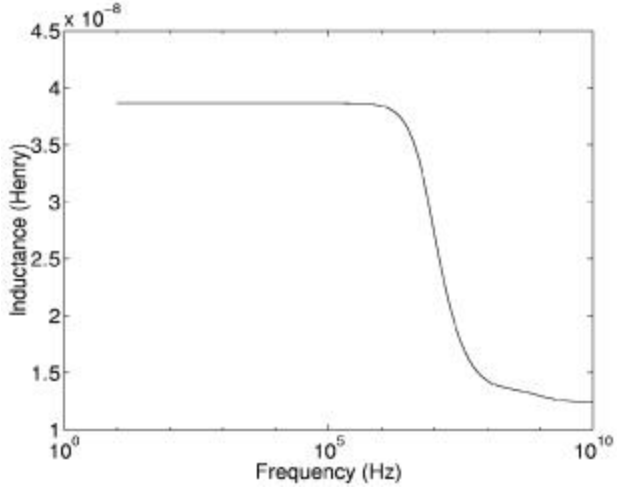
Current Status



Spiral Inductor Suspended over a Copper Plane



Fast Solver + Model Order Reduction ~ hours

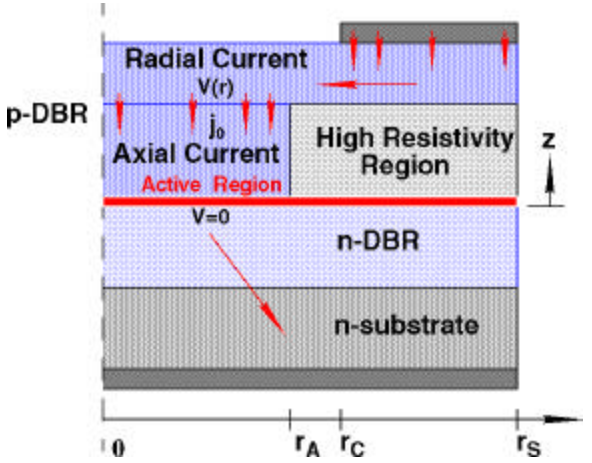


Linear Analysis – Automated!

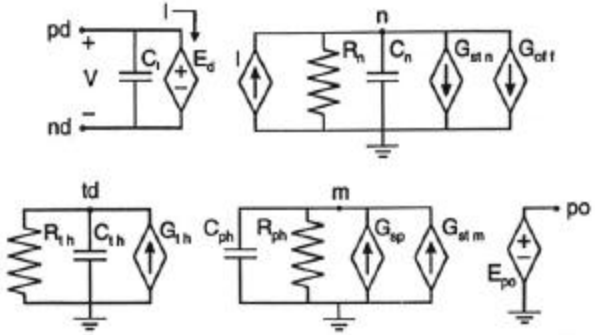
Design Automation

- Linear Analysis is Lending itself to Automation
- Need Breakthroughs for Non-Linear Analysis **(Very Important for Mixed Signal Design)**
- Design Approach for Photonic Devices & Circuits is still ad hoc

VCSEL Device

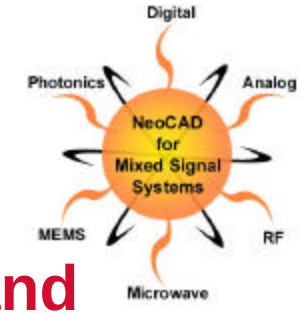


Circuit Models for VCSELs



Not Automated !!

NeoCAD Approach

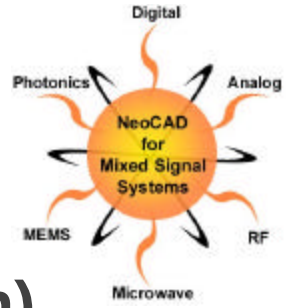


Implement Advanced Automation Methods and Techniques for the Design, Verification and Optimization of Mixed Signal Circuits and Components; Demonstrate Impact on Military Relevant Mixed Signal Systems

Task 1.	**Develop Fast Solvers for Extraction of Parasitics**
Task 2.	**Develop Physics Based Behavioral Models and Model Libraries**
Task 3.	**Develop Automated Synthesis Tools; Integrate with Digital EDA Tools**
Task 4.	**Demonstrate Tools on Advanced Military Applications in Collaboration with Other DARPA Programs**

This approach has the potential for improving design cycle time and cost by a factor of 10-100 !!

Task 1. Fast Solvers



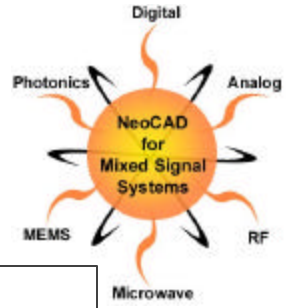
Innovative Fast Solvers to Perform Linear and Non-Linear Analysis (and Automated Extraction) of Mixed Signal Circuit Parasitic Effects on Signal Integrity

Challenges

- **Fast Algorithms for Inductance/Capacitance Calculation and Transmission Line Effects, Substrate Noise and EM Coupling, Switching Noise, Thermal Noise, etc.**
- **Linear and Non-Linear Interactions**

Fast and Automated Extraction of Parasitics from Circuit Layout

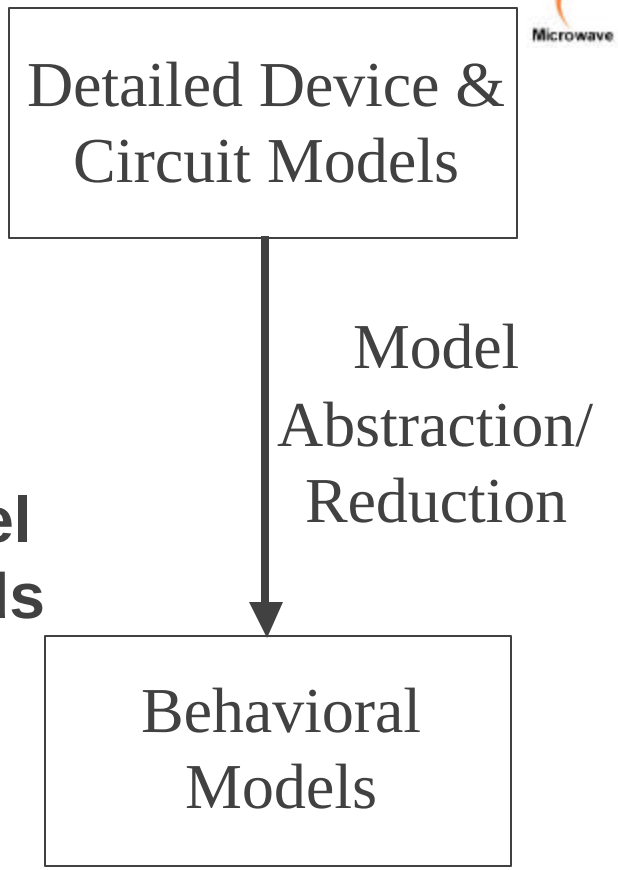
Task 2. Behavioral Models



Physics Based Behavioral Models

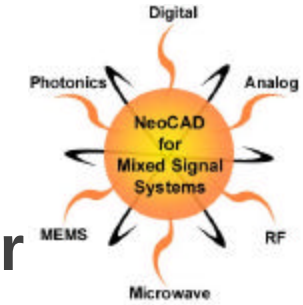
Challenges

- Models for Emerging High Performance Device Materials and Architectures
- Non-Linear, Time-Varying Model Order Reduction (MOR) Methods
- Generate Device and Circuit-Level Behavioral Models and Model Libraries



Methods to Generate Behavioral Models and Model Libraries for Mixed Signal Components and Circuits

Task 3. Automated Synthesis Tools



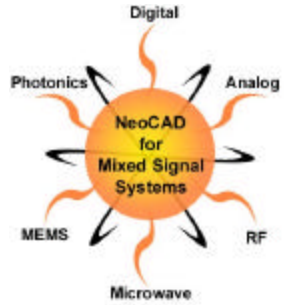
Develop an Automated Synthesis Capability for Integrated Mixed Signal Systems

Challenges

- **Implement Effect of Circuit Parasitics on Behavioral Models**
- **Implement Methodologies for Digital-Analog Co-Design**
- **Implement Rules for Synthesis and Layout of Mixed Signal Components & Circuits**
- **Circuit Design Verification & Optimization**

Development of Mixed Signal and Mixed Electronic/Photonic Design Capability

Task 4. Tool Demonstration

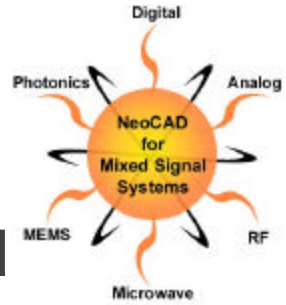


Demonstration of Design Tool in Prototyping Mixed Signal and Mixed Electronic/Photonic Circuits; Identify Military Relevant Applications

- **Mixed Electronic/Photonic System: e.g., Integrated Circuit with VCSELS and Photodetectors on a Chip**
- **Mixed Digital/Analog Design: e.g., High Performance A-D Converter for Sensing and Communication Applications**

Demonstration of 10-100x Improvement in Cycle Time & Cost of Designing Above Systems

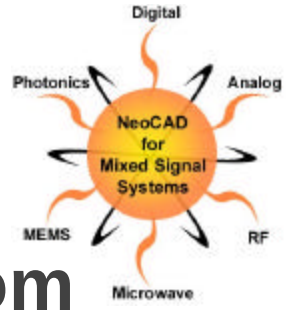
Impact of NeoCAD



- It will put in place the first set of Automated Design Tools for:
  - Mixed Signal (Analog/Digital) Design
  - Integrated Photonics and Electronics
- It will enable:
  - A new revolution in mixed signal systems for dual use applications through enhanced design innovations
  - Reduction in design cycle time & cost of 10-100x by eliminating the 'expert in the loop'

Significant Impact on Design of Military Systems !

Technology Transition



- The program will engage companies from digital EDA, Mixed Signal Design, Optical CAD and universities and small businesses to maximize opportunities for technology transition

- The Biggest Market/Application Pulls Today :

  - Wireless Communication – Mixed Digital/ Analog Design
  - Optical Devices - Integrated Photonics and Electronics, Optical MEMS(MOEMS)